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Embedded Star Formation in the Eagle Nebula

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ABSTRACT

M16=NGC 6611, the Eagle Nebula, is a well studied region of star formation and the source of a widely recognized Hubble Space Telescope (HST) image. High spatial resolution infrared observations with the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) on HST reveal the detailed morphology of two embedded star formation regions that are heavily obscured at optical wavelengths. It is striking that only limited portions of the visually obscured areas are opaque at 2.2 microns. Although the optical images imply substantial columns of material, the infrared images show only isolated clumps of dense gas and dust. Rather than being an active factory of star production, only a few regions are capable of sustaining current star formation. Most of the volume in the columns may be molecular gas and dust, protected by capstones of dense dust.

Two active regions of star formation are located at the tips of the optical northern and central large "elephant trunk" features shown in the WFPC2 images. They are embedded in two capstones of infrared opaque material that contains and trails behind the sources. Although the presence of these sources was evident in previous observations at the same and longer wavelengths, the NICMOS images provide a high resolution picture of their morphology. Two bright stars appear at the tip of the southern column and may be the result of recent star formation at the top of that column. These observations suggest that the epoch of star formation in M16 may be near its endpoint.

Subject headings: Star Formation

1. Introduction

Dramatic optical pictures of M16 taken with WFPC2 on HST (Hester et al. 1996) show three large columns or elephant trunks of molecular gas and dust that are shaped by the stellar wind and radiation pressure from high luminosity young stars a few arc minutes away. The columns are designated I, II, and III going north to south. The morphology of the columns clearly indicates that the initial high mass star formation in a molecular cloud region plays a large role in subsequent star formation by altering the density structure of the gas and dust in the surrounding region. Large areas of low density are cleared of material while regions of higher density form elongated structures extending radially away from the cluster of newly formed stars. The elongated trunk structures are repeated on a smaller scale with "fingers" and "eggs" of material throughout the larger structure.

It has generally been assumed that new star formation is occurring inside the trunk and egg structures and that gravitational attraction of the protostellar condensations is retaining the material against the action of the radiation pressure and stellar wind from the nearby young stars. Earlier infrared observations by Hillenbrand et al. (1993) indeed revealed significant previous star formation that was not easily visible by optical means, although they limited their quantitative analysis mainly to objects with detectable visible flux. They determined that there are stars up to 80 $M_{\odot}$ in the visible OB association and that there are intermediate mass stars still above the main sequence, assuming their distance of 2 kpc which we will adopt in our analysis. The embedded sources discussed here are clearly visible in their image, but were not remarked upon individually as they were not detected in the optical image. They also do not appear in their table of embedded infrared sources. The non-stellar morphology of the sources is not clearly apparent in their published image, although there is nebulosity near the source locations. There is also evidence for both sources (which we label M16ES-1 and M16ES-2 for M16 Embedded Source 1 and 2) in the WFPC 2 F547M images. M16ES-2, visible as a diffuse reflection nebulosity, was first described by Hester (1997).

Although at lower resolution and much brighter limiting magnitude, M16ES-1 and 2 are clearly visible in the near infrared image of M16 by McCaughrean (1997), however, they are not commented on in the text. In this black and white rendering of a portion of a much larger 3 color (J,H,K) image the transparency of large sections of the columns is clearly apparent. McCaughrean (1997) comments that at the limiting magnitude of the image only 10% of the eggs labeled by Hester et al. (1996) appear to contain forming stars or chance coincidences with background sources.

Work done on the optical emission line images of the region (Hester et al. 1996) demonstrated the influence of photoevaporation on the morphology of the gas and dust. In the absence of any other effects, photoevaporation will eventually destroy the region leaving

only those stars that managed to form before the destruction. The observations discussed in this paper are part of a program to study the detailed morphology of the embedded star formation in the trunks and to study the effects of embedded star formation on the subsequent evolution of the region. A detailed analysis of the sources in the region is in preparation (Smith et al. 2002; Hester 2002).

2. Observations

The observations utilized the NICMOS camera 3 during the HST NICMOS camera 3 campaign of January 1998. During the campaign the HST secondary mirror was adjusted slightly to achieve the best camera 3 focus. Observations were taken in columns I and II at four different positions to cover areas also observed with WFPC2. A fifth position in column III was also observed later with the higher resolution camera 2. The camera 3 images are in the F110W, F160W, and F222M wide and medium band filters, while the camera 2 images are in the F110W, F160W and F205W filters. All observations are four point dithered with a total of 768 seconds of integration in the F222M and F205W filters and 704 seconds in the F110W and F160W filters. The pixel size of camera 3 is 0.2 arc seconds which gives a 51 by 51 arc second field of view for each of the 4 camera 3 observations. Camera 2 has a pixel size of 0.075 arc seconds for a 15 by 15 arc second field of view.

In addition to the continuum images, the position at the head of column I was also imaged in molecular hydrogen and atomic hydrogen. The line and continuum narrow band filters, F187N and F190N, isolate the atomic hydrogen Paschen α line while the F212N and F215N filters isolate the H_2 S(1) line. Again four dither positions were utilized with 96 and 160 second integrations for each position in Paschen α and H_2 respectively.

3. Data Reduction

The NICMOS images were reduced utilizing IDL based procedures developed for image production in the Hubble Deep Field (Thompson et al. 1999). The individual dither position images for each filter were then aligned and the median image calculated via an additional IDL software interactive procedure called IDP3 (Lytle et al. 1999). The associated continuum images were subtracted from the line filter images to produce the final Paschen α and H_2 emission line images.

4. Infrared Morphology

Figure 1 is a color image of the infrared observations with the RGB colors corresponding to the F222M, F160W and F110W (2.2, 1.6, and 1.1 μm) filters respectively. This image shows that, rather than being dense columns of gas and dust, there are only a few regions of the elephant trunks that contain high concentrations of dust. The heads of columns I, II and III contain dense dust capstones, however, most of column I has a low dust column density. The limited spatial coverage precludes a similar statement from our data for column II but there is an obvious thinning of dust away from the column head. Inspection of the McCaughrean (1997) image confirms that this thinning continues until another capstone dust region occurs to the southeast. Below the dust region at the top of the column I there is a large region of low dust density and then several areas of higher dust density to the southeast. Each of these have similar geometries which point back toward the OB cluster. The high density dust regions in both columns have sub-structures that appear to point back to the embedded sources at the top of the columns. This suggests that, although the overall geometry of the columns is controlled by the radiation and stellar wind from the O star complex, the geometry of the smaller dense regions may be affected by local sources. Section 8 discusses this possibility.

Although there is a very high density of stellar sources, not evident in the optical images, the darkness of the high density regions indicates that the majority of the stellar sources lie behind the columns. Since the position of M16 is very close to the direction of the galactic center, many of the fainter sources may be stars in the galactic plane, not associated with the M16 complex. An extensive foreground screen of dust, not directly associated with the columns, obscures the stars from view at optical wavelengths.

Fig. 2 shows the camera 2, higher resolution, image of the tip of column III. The tip of column III is concave and 2 bright stars reside in that region. These stars are too bright to be distant background stars but the density of stars of similar brightness in the images indicates that is a non-negligible chance that their location in the concave region of the tip could be just chance coincidence. The possibility that the two stars recently formed in the tip of the column is discussed in Section 9. Following the lead of our nomenclature for the embedded sources we label the two stars M16S-1 and M16S-2.

The location of high density dust regions at the leading faces of the columns and the morphology of those regions is supportive of the idea that shocks, driven in advance of the ionization front are important in compressing the columns. The location of the two embedded sources at the very leading edge of the columns further supports this concept. The sparsity of high density dust regions also supports the suggestion (Hester et al. 1996) that photoevaporation is disrupting as well as triggering active star formation.

The lack of dense dust in the columns below the two embedded sources and their associated dust structures is consistent with the radio, sub-mm, and infrared maps presented by White et al. (1999) and the near infrared images of McCaughrean (1997). These maps and images show strong emission at the locations of the embedded sources but very little emission along the columns until another area of strong emission to the southeast, beyond the extent of our images. CO maps by White et al. (1999) indicate that there is molecular gas along the whole length of the columns but that its density is far less than at the location of the sources. The combination of the near infrared images and the longer wavelength observations show that only limited areas of the columns are capable of sustaining current star formation, which explains the observation of Pilbratt et al. (1998) that the star formation rate in the columns, based on the mid-infrared flux, appears to be very low. The eastward color gradient in the background from dark to red in fig. 1 is due to thermal emission in the F222M band increasing from the relatively dust free region above the columns to the dustier area of the columns.

Fig. 3 shows the individual infrared continuum images along with the well known optical image. Comparison of the infrared images with the optical indicates that most of the dust structures observed in the optical are identifiable in the infrared image. In particular each "finger" structure observed in the optical appears to have a capstone of dense dust. The blue nebulosity near the heads of the columns and along the edges of the dust regions in fig. 1 is probably emission from hydrogen Paschen β and possibly He I 10830. Both of these lines are in the passband of the F110W filter. Two clearly non stellar amorphous sources (M16ES-1 and M16ES-2) lie at the tops of columns I and II and appear to be emerging from the high dust density regions. The positions of these sources, based on the World Coordinate System (WCS) of the images are given in Table 1. We have not performed astrometry on the stars in the images, so these positions are only as accurate as the guide star positions. A typical uncertainty on guide star positions is $\pm 1''$.

It is not clear whether the sources are clusters of stars or reflection nebulosities created by single sources. The lack of Paschen α emission at the position of M16ES-1 indicates that it must either be a cluster of relatively low mass stars or an object (or objects) that has not yet reached the main sequence (Sec. 7). We will assume that both sources are star formation sources, based solely on their association with the high density dust regions. Sections 5 and 6 discuss these sources more thoroughly.

In addition to the two amorphous embedded sources near the tops of the columns, at least three other point-like sources are visible at the tips of fingers and at the top of a nearby dense dust region. One finger source is at the tip of a very thin finger, M16-E42 (Hester et al. 1996), in the southwest corner of the lower image of column I. It is also visible in

the optical image of the same area in Fig. 3. The thin finger is easily visible in the optical and F110W images but is difficult to detect in the longer wavelength images. Another finger source is just to the north of the first finger source, is at the top of the adjacent broader finger of dust (M16-E39). This point-like source is visible in all of the infrared images but not in the optical. Although unlikely, we can not rule out that it is a chance superposition of a background star given the high density of stars in the region. Finally there is a very bright point source on the shoulder of a dust region just northeast of the the very bright star in the WFPC image that falls just off the NICMOS images. This source is at the location of a photoionized surface (M16-E33). All of these sources will be discussed more thoroughly in a future publication (Hester 2002).

4.1. Extinction and Density in the Columns

It is useful to get an estimate of the extinction and density of the material in column I. Sophisticated treatments of extinction utilizing J, H, and K near infrared colors such as NICE (Lada, Alves and Lada 1999) and NICER (Lombardi and Alves 2001) have been developed. Unfortunately our images have significant emission in two of our bands, Pa β and He 10830 in the F110W band and thermal emission in the F222M band which complicates these analyses. Instead we use a simpler technique that compares the average magnitude of the stars in the F160W image both in and out of the columns. We will consider two regions in column I, a region in part of the dark capstone of column I and a mid-column region where the column appears quite transparent. Two reference regions above the columns are chosen to be clear of the dust associated with the columns. The position of all of the regions are shown in Fig. 3. We utilized the DAOPHOT photometric analysis program (Stetson 2001) to measure the magnitudes of the stars in the image down to a Vega magnitude of 19. For the two regions a and b above the columns the average magnitudes are 17.26 and 17.13 for 173 and 102 stars respectively. In the intra-column region c the average magnitude was 17.58 for 91 stars. The average uncertainty in magnitude for the regions is 0.12 magnitudes. From this we conclude that the intra column region has an extinction of 0.4 ± 0.2 magnitudes at 1.6 μm.

If the dust in column I follows the same extinction law as the dust near the star VI Cyg No. 12 the ratio of extinction at 1.6 μm to V is 0.175 (Rieke and Lebofsky 1985) giving a visual extinction of 2.3 ± 1.2 magnitudes. The empirical relation between X-ray absorption and optical extinction (Seward 1999) gives $N_H/A_V = 1.9 \times 10^{21}$ atoms cm^{-2} mag^{-1}. This leads to a column density of hydrogen in the region of $(4.4 \pm 2.2)\ \times 10^{21}$ hydrogen atoms cm^{-2}. If we assume that the columns depth is roughly equal to its width we get a depth of

about 8×10^{14} cm and a hydrogen density of $(5.5 \pm 2.8) \times 10^{6}$ H atoms cm^{-3}. If the hydrogen in primarily molecular the number density of molecules will be 1/2 this value. This density is the same as for a high density molecular cloud but the extinction is low because of the small column depth.

In the dark region d of column I we do not detect any stars. Aperture photometry of individual stars indicates that stars at a F160W magnitude of 23 are readily detectable. Even if we limit the background stars in the dark area to the average magnitude of 17.2, the lower limit on the extinction at 1.6 μm is 6 magnitudes. The extinction is most likely more than this value as there are probably stars several magnitudes brighter than 17.2 behind the area. Using the same arguments as above, the visual extinction in the dark area is at least 34 magnitudes and the hydrogen column density at least 6.5×10^{22} H atoms cm^{-2}. This is of course a lower limit and the actual extinction and density are most likely many times the numbers used here.

5. Photometry and Luminosity of the Sources

Precision photometry of the embedded sources is difficult due to the extended morphology and underlying emission. We chose a circular aperture of 2 arc seconds radius for our photometry. Although there is emission outside of this radius it appears that most of the flux is inside the area. We estimate the underlying emission by averaging over a circular annulus of inner and outer radii of 3 and 6 arc seconds centered on the embedded source. Both of these procedures will tend to underestimate the flux if the source flux extends beyond the 2 arc second radius or if source flux also lies in the annulus used for background flux calculation. The results of this simple photometry are given in Table 1. Note that although the F160W and F222M filters correspond closely to the usual H and K bands, the F110W filter is much bluer than the usual J band.

We can use the mid and far infrared observations compiled by White et al. (1999) to estimate the luminosities of the embedded sources. Both have strong radio, SCUBA, MSX, and ISOCAM sources centered on their locations. To estimate the luminosities, we take the long wavelength fluxes in Fig. 3 of White et al. (1999) and integrate under the curves to get the long wavelength luminosity. To estimate the shorter wavelength luminosity we use our measured photometry and the mid-IR fluxes from the MXS data base maintained at IPAC (M16ES-1 only). We then extend the mid-IR flux to 200 microns by drawing a straight line in the log wavelength versus log flux plot to intersect the long wavelength plot at 200 microns and again integrate under the curves. This probably underestimates the flux between 14 μm and the far-IR giving a lower limit on the luminosity. The luminosities determined in this

manner are 200 (+50, -25) and 20 (+10,-5) $L_{\odot}$ for M16ES-1 and 2 respectively. Each of these luminosities could be for a single object or for a cluster of objects if the nonstellar images are due to a group of forming stars as opposed to a reflection geometry. Unfortunately the ISOCAM fluxes of Pilbratt et al. (1998) do not list the integrated fluxes at the sources. They only list the fluxes of point-like objects away from the positions of the embedded sources. The ISOCAM images from that work, presented by White et al. (1999), clearly show strong extended emission at the locations of both embedded sources.

6. Morphology of the Embedded Star Formation Region

M16ES-1 and M16ES-2 appear non-stellar in all of the infrared images. M16ES-1, however, may have a strong point-like component. The F110W image in Fig. 3 clearly shows a dust bar that runs across the location of M16ES-1. The main component of M16ES-1 in the F222M image is at the western edge of the bar. The peak of emission is almost point-like with an extension to the northwest. This hints that the extended nature of the emission may be primarily due to reflection off nearby dust structures. In all filters there is nebulosity to the north of M16ES-1 which is most likely a combination of reflected light from M16ES-1 and the emission from gas ionized by the O stars. All three of the NICMOS continuum filters contain emission lines in their bandpasses. M16ES-2 is less extended with nebulosity extending toward the east. The intensity of the nebulosity relative to the source increases with decreasing wavelength. Hester (1997) suggests that M16ES-2 is currently emerging from its surrounding dust cloud via photoevaporation. At a low stretch the image of M16ES-2 appears to be double with surrounding nebulosity. Polarimetry with a revived NICMOS will be able to separate a point source or sources from the reflected components.

7. Emission Line Morphology

Fig. 4 shows the emission in hydrogen Paschen α, hydrogen Hα, the H_2 S(1) line at 2.12 μm, and the 2.2 μm continuum at the position of M16ES-1. The other locations do not have line images. These figures show the locations of the ionized and molecular gas as well as the area of high dust concentration. The H_2 image shows the extent of the molecular gas which conforms well with the dust regions shown by the 2.2 μm continuum image. The exception is the area just above the embedded source where the structure seen in the H_2 image is absent. This is probably due to hydrogen Brackett γ emission, which falls in the F222M filter band, hiding the structure. The strong atomic hydrogen emission above the embedded source (in the direction of the O star cluster) is due to a local HII region ionized by the radiation from

the O star cluster. The ionized gas is the result of photo-evaporation of gas from the head of the column as described in Hester et al. (1996), although it is possible that M16ES-1 may also have a role in moving gas into this ionized region. Both the Hα and the Paschen α images show emission where the ionizing radiation from the cluster strikes the surface of the dust and molecular cloud. The mechanisms for this surface emission are detailed by Hester et al. (1996).

The absence of Paschen α emission at the location of M16ES-1 indicates that it is not a source of ionizing radiation. This observation rules out M16ES-1 as a single ZAMS star. At a luminosity of $200L_{\odot}$ it would be a B6-B7 star on the main sequence producing an HII region with a $\log N_e^2 V = 53.9$ (Thompson 1984). This would produce detectable flux in Paschen α. Its absence indicates that either the source is made up of multiple, lower luminosity objects or that it is an object or objects that has not yet reached the ZAMS. We cannot comment similarly on M16ES-2 as there is no Paschen α image for that source.

Above the embedded source the morphology of the H_2 emission is quite different from the ionized hydrogen emission. The lack of molecular material in this region confirms that most of the gas in the area has been ionized by the O star cluster stars. Below the embedded source the H_2 emission follows the same structure as the atomic hydrogen emission, defining the surface of the dust and molecular cloud. This suggests that the H_2 emission may be due to photo-excitation (Black and van Dishoeck 1987) rather than by shock excitation. Unfortunately, with only an image in one line, we can not discriminate between the two emission processes, however, near infrared Fabry-Perot images of the heads of the columns (Allen et al. 1999) indicate that the majority of the H_2 emission is from fluorescent photo-excitation.

8. Local Source Geometry

The infrared images of the dust clouds associated with M16ES-1 and 2 show dust tendrils that point directly toward the embedded sources. This strongly suggests that, although the general structure of the M16 columns is determined by the O star cluster, local dust and molecular structures are being influenced by the embedded sources. The concentration of the dense dust capstones into a cone of approximately 60 degrees in width on the side away from the O star cluster attests to the strong influence of the cluster radiation on the dust structure. To assess the roles of each, we can make some elementary estimations based on the relative luminosities and distances of the O star cluster and the embedded sources. Taking the cluster luminosity as $2 \times 10^6 L_{\odot}$ from the O star luminosity and the M16ES-1 luminosity as $200L_{\odot}$, along with a distance between the cluster and the source of 2 parsecs, we find that

at distances less than 0.02 parsecs the radiation pressure from the embedded source exceeds that from the cluster. Here we have assumed that the absorption efficiency of the gas and dust is independent of the spectrum of the radiating source. At the distance of M16, 0.02 pc is about 2 arc seconds on the sky which is less than the size of the dust tendrils in dense dust regions. This probably means that the embedded sources only influence the local structure in regions where the gas and dust are well shielded from the OB association radiation, such as the tendrils seen behind the capstone dust areas. On larger scales the radiation pressure from the O star cluster prevails, and the material enters the general trail of material swept up by the cluster radiation field.

9. Column III Sources

The crescent area at the top of column III contains two stars, MS16S-1 and MS16S-2, both with F205W Vega system magnitudes of 13.2. The northern star (Star 1 in Fig. 2) has a slightly redder color with an F110W Vega magnitude of 17.3 as opposed to 17.0 for the southern star (Star 2). Table 1 gives the full set of magnitudes for the two stars. We assume the red color of these stars is due to the foreground screen of dust that covers the entire extent of the three column structure. Given the similarity of the two stars it is appropriate to ask if they are physically associated, whether they formed in column III and whether the crescent shape of the tip of column III represents a cavity produced by a combination of the radiation pressure from the two stars and the much stronger radiation pressure from the OB association. If the stars are at the 2 kpc distance of M16 their 2 μm absolute magnitude is 1.7, assuming no extinction at 2 μm. This would place them at about spectral type A3 on the main sequence with luminosities on the order of 30 $L_{\odot}$. If there is extinction at 2 μm, as there surely must be, the two stars will have luminosities greater than 30 $L_{\odot}$.

The radius of the crescent in the tip of column 3 is about 10 arc seconds which is equal to 0.1 pc at the distance of M16. It is doubtful that stars with a combined luminosity of 60 $L_{\odot}$ would produce a cavity of 0.1 pc but they would certainly reduce the density in the immediate region around them. The radiation from the OB association would then have an easier time photoevaporating that region, creating the observed crescent cavity. This may be one mechanism for dividing the main column into many substructures. If M16S-1 and 2 are indeed stars that formed at the tip of the column we are seeing a snapshot of three stages of star formation in the columns, going from embedded in column I, to emerging in column II, to completely emerged in column III.

10. Conclusions

There are at least two currently active areas of star formation in the columns of M16. Both are near the tops of the columns which face the cluster of luminous O stars. Although the optical images show significant extinction throughout the columns, the infrared images show that the density of dust and molecular gas is quite low, except at the location of the embedded sources and at isolated areas along the columns to the southeast. Far infrared images show another strong emission area to the southeast, beyond the extent of our images. It appears that this region of M16 is in its last stage of star formation and the dissipation of the columns may soon follow as the material in the few dense clumps is exhausted. This explains the relatively low rate of star formation commented on by Pilbratt et al. (1998). An alternative is that further star formation will be triggered in the columns as the photocompressed region moves down the length of each column.

The dust and molecular gas in the columns away from the dust structures has a high enough density to be opaque to optical emission but not enough to produce high amounts of current star formation. CO emission along the columns indicates that the amount of dust is sufficient to shield some molecular gas from dissociation. The dense gas and dust at the locations of the two embedded sources act as capstones, shadowing much of the column from the ionizing radiation of the O star cluster. The O star cluster, however, has a significant angular extent, and ionizing radiation does fall on the surface of the columns. The detailed interaction with the surface is described by Hester et al. (1996).

The lack of ionizing radiation from M16ES-1 indicates that it is either a cluster of relatively low mass stars or an object or objects that have not yet evolved to the Zero Age Main Sequence. The line emission in atomic hydrogen is due to photo-ionization and photo-excitation by radiation from the O star cluster. The morphology of the dust near the embedded sources suggests that they have a role in determining the local structure. The elementary calculations of Sec. 8 indicate that the sources have sufficient strength to affect their surroundings, but only in regions well shielded from the radiation from the OB association. The restriction of the dust regions to a relatively narrow cone that points in the direction of the O star cluster shows that the cluster radiation plays the primary role in the dust and gas dynamics at the site of the embedded sources.

High resolution camera 2 images show two bright stars of very similar magnitude and color within the concave depression in the tip of column III. These may be a chance superposition of local background stars on this location. The stars, however, may have formed in the tip of the column. If so the stars may have reduced the density in their surroundings enough to allow the photoevaporation from the O star cluster to be much more efficient in this area, forming the current concave depression in the column tip. The three columns

would then show a sequence of star formation stages from embedded in column I, emerging in column II, and fully emerged in column III.

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Table 1. Source Fluxes, Vega Magnitudes, Luminosities and Positions

Source	F110W mJy	F110W mag	F160W mJy	F160W mag	F222M [a] mJy	F222M [a] mag	Lum. $L_\odot$	R.A. J2000	Dec. J2000
M16ES-1	0.85	15.8	4.3	13.5	25.	11.1	200	$18^h\ 18^m\ 50.29^s$	$-13^\circ\ 48'\ 55.2''$
M16ES-2	0.3	16.9	0.4	16.1	0.66	15.0	20	$18^h\ 18^m\ 48.64^s$	$-13^\circ\ 49'\ 50.9''$
Star 1	0.21	17.3	8.1	12.8	3.8	13.2	30	$18^h\ 18^m\ 48.75^s$	$-13^\circ\ 50'\ 38.6''$
Star 2	0.27	17.0	9.0	12.7	3.9	13.2	30	$18^h\ 18^m\ 48.79^s$	$-13^\circ\ 50'\ 40.4''$

[a]This is F205W for the last two entries

Fig. 1.— Infrared image of the observed regions of Column I and II. Blue, green and red in the image correspond to the F110W, F160W, and F222M NICMOS filters. The stretch is square root and has been adjusted to enhance the visibility of the sources. The blue emission surrounding the columns is most likely Paschen β and He 10830 that lie in the F110W filter. All portions of the image have the same stretch. North is up and east is to the left as shown by the compass points. Each square field of view is $51''$.

Fig. 2.— Infrared image of the observed region in Column III with camera 2. The image uses the F110W, F160W, and F205W NICMOS filters, represented by blue, green, and red. The stretch is linear and has been adjusted to enhance the visibility of the sources. As in Fig. 1 the blue emission surrounding the column is most likely Paschen β and He 10830 that lie in the F110W filter. The red round region to the north of the dark column II is thermal emission from the coronagraphic hole in camera 2. It is not perfectly round since it is the image from 4 offset points in the dither pattern. When the images are added with the stars aligned the coronagraphic hole images are slightly misaligned. The square field of view is $17''$.

Fig. 3.— The same region of the M16 columns in the optical from WFPC2 and the three NICMOS infrared images at 1.1, 1.6 and 2.2 μm. All of the images have a linear stretch. The regions marked a, b, c and d in the F160W image indicate the regions used in the extinction and density analysis of column I described in section 4.1. As in fig. 1 each square field of view is $51''$.

Fig. 4.— Four images of the same region at the top of column 1 in Paschen α, H α, H_2, and 2.2μm continuum. All regions have the same scale and orientation and the intensity scale is linear in ADUs per second. Subtraction of the continuum image can produce negative values in the line emission images since the psfs of the line and continuum are slightly different due to their differing wavelengths. This produces dark holes at the positions of bright stars. The square field of view is $51''$.